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GEOLOGICAL HISTORY OF THE YELLOWSTONE NATIONAL PARK

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GEOLOGICAL HISTORY OF THE YELLOWSTONE NATIONAL PARK.

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The purpose of this paper is not so much to elucidate any special problem connected with the many interesting geological questions to be found in the Yellowstone Park, as to offer such a general view of the region as will enable the tourist to understand clearly something of its physical geography and geology.

The Yellowstone Park is situated in the extreme northwestern portion of Wyoming. At the time of the enactment of the law establishing this national reservation the region had been little explored, and its relation to the physical features of the adjacent country was little understood. Since that time surveys have shown that only a narrow strip about 2 miles in width is situated in Montana and that a still narrower strip extends westward into Idaho.

The area of the park as at present defined is somewhat more than 3,300 square miles.

The Central Plateau, with the adjacent mountains, presents a sharply defined region, in strong contrast with the rest of the northern Rocky Mountains. It stands out boldly, is unique in topographical structure, and complete as a geological problem.

The central portion of the Yellowstone Park is essentially a broad, elevated, volcanic plateau, between 7,000 and 8,500 feet above sea level, and with an average elevation of about 8,000 feet. Surrounding it on the south, east, north, and northwest are mountain ranges with culminating peaks and ridges rising from 2,000 to 4,000 feet above the general level of the inclosed table-land.

For present purposes it is needless to confine ourselves strictly to legal boundaries, but rather to consider the entire region in its broader physical features.

South of the park the Tetons stand out prominently above the surrounding country, the highest, grandest peaks in the northern Rocky Mountains. The eastern face of this mountain mass rises with unrivalled boldness for nearly 7,000 feet above Jackson Lake. Northward the ridges fall away abruptly beneath the lavas of the park, only the outlying spurs coming within the limits of the reservation. For the most part the mountains are made up of coarse crystalline gneisses and schists, probably of Archean age, flanked on the northern spurs by upturned Paleozoic strata. To the east of the Tetons, across the broad valley of the Upper Snake, generally known as Jackson Hole, lies the well-known Wind River Range, famous from the earliest days of the Rocky Mountain trappers. The northern end of this range is largely composed of Mesozoic strata, single ridges of Cretaceous sandstone penetrating still farther northward into the regions of the park and protruding above the great flows of lava.

THE ABSAROKA RANGE ALONG THE EASTERN EDGE OF THE PARK.

Along the entire eastern side of the park stretches the Absaroka Range—so called from the Indian name of the Crow Nation. The Absaroka Range is intimately connected with the Wind River Range, the two being so closely related that any line of separation must be drawn more or less arbitrarily, based more upon geological structures and forms of erosion than upon physical limitations.

The Absarokas offer for more than 80 miles a bold, unbroken barrier; a rough, rugged country, dominated by high peaks and crags from 10,000 to 11,000 feet in height. The early trappers found it a forbidding land; prospectors who followed them, a barren one.

At the northeast corner of the park a confused mass of mountains connects the Absarokas with the Snowy Range. This Snowy Range shuts in the park on the north and is an equally rough region of country, with elevated mountain masses covered with snow the greater part of the year, as the name would indicate. Only the southern slopes, which rim in the park region, come within the limit of our investigation. Here the rocks are mainly granites, gneisses, and schists, the sedimentary beds, for the most part, referable to the pre-Cambrian series.

The Gallatin Range incloses the park on the north and northwest. It lies directly west of the Snowy, only separated by the broad valley of the Yellowstone River. It is a range of great beauty, of diversified forms, and varied geological problems. Electric Peak, in the northwestern corner of the park, is the culminating point in the range, and affords one of the most extended views to be found in this part of the country.

THE GALLATIN RANGE IN THE NORTHEASTERN PORTION OF THE PARK.

Archean gneisses form a prominent mass in the range, over which occur a series of sandstones, limestones, and shales, of Paleozoic and Mesozoic age, representing Cambrian, Silurian, Devonian, Carboniferous, Trias, Jura, and Cretaceous. Immediately associated with these sedimentary beds, are large masses of intrusive rocks, which have played an important part in bringing about the present structural features of the range. They are all of the andesitic type, but show considerable range in mineral composition, including pyroxene, hornblende, and hornblende-mica varieties. These intrusive masses are found in narrow dikes, in immense interbedded sheets forced between the different strata, and as laccolites, a mode of occurrence first described from the Henry Mountains in Utah, by Mr. G. K. Gilbert, but now well recognized elsewhere in the northern Cordillera.

We see then that the Absarokas rise as a formidable barrier on the eastern side of the park, the Gallatins as a steep mural face on the west side, while the other ranges terminate abruptly, rimming in the park on the north and south, and leaving a depressed region not unlike the parks of Colorado, only covering a more extended area with a relatively deeper basin. The region has been one of profound dynamic action, and the center of mountain building on a grand scale.

It is not my purpose at the present time to enter upon the details of geological structure of these ranges, each offering its own special study and field of investigation. My desire is simply to call attention to their general features and mutual relations. So far as their age is concerned, evidence goes to show that the action of upheaval was contemporaneous in all of them, and coincident with the powerful dynamic movements which uplifted the north and south ranges, stretching across Colorado, Wyoming, and Montana. This dynamic movement blocked out, for the most part, the Rocky Mountains, near the close of the Cretaceous, although there is good reason to believe that in this region profound faulting and displacement continued the work of mountain building well into the Middle Tertiary period.

Throughout Tertiary time in the park area, geological history was characterized by great volcanic activity, enormous volumes of erupted material being poured out in the Eocene and Middle Tertiary, continuing with less force through the Pliocene, and extending into Quaternary time. Within very recent times there is no evidence of any considerable outburst; indeed the region may be considered long since extinct. These volcanic rocks present a wide range in chemical and mineral composition and physical structure. They may all, however, be classed under three great groups—andesites with basalts, rhyolites, and basalts—following each other in the order named. In general, the relative age of each group is clearly and sharply defined, the distribution and mode of occurrence of each presenting characteristics and salient features frequently marked by periods of erosion.

Andesites are the only volcanic rocks which have played an important part in producing the present structural features of the mountains surrounding the park. As already mentioned, they occur in large masses in the Gallatin Range, while most of the culminating peaks in the Absarokas are composed of compact andesites and andesitic breccias. On the other hand, the andesites are not confined to the mountains, but played an active rôle in filling up the interior basin. That the duration of the andesitic eruptions was long continued is made evident by the plant remains found in ash and lava beds through 2,000 feet of volcanic material.

In early Tertiary times, a volcano burst forth in the northeast corner of this depressed area not far from the junction of the Absaroka and Snowy Ranges. While not to be compared in size and grandeur with the volcanoes of California and the Cascade Range, it is, for the Rocky Mountains, one of no mean proportions. It rises from a base about 6,500 feet above sea level, the culminating peak attaining an elevation of 10,000 feet. This gives a height to the volcano of 3,500 feet from base to summit, measuring from the Archean rocks of the Yellowstone Valley to the top of Mount Washburn. The average height of the crater rim is about 9,000 feet above sea level, the volcano measuring 15 miles across the base. The eruptive origin of Mount Washburn has long been recognized, and it is frequently referred to as a volcano. It is however simply the highest peak among several others, and represents a later outburst which destroyed in a measure the original rim and form of an older crater. The eruptions for the most part were basic andesites. Erosion has so worn away the earlier rocks, and enormous masses of more recent lavas have so obscured the original form of lava flows, that it is not easy for an inexperienced eye to recognize a volcano and the surrounding peaks as the more elevated points in a grand crater wall. By following around on the ancient andesitic rim, and studying the outline of the old crater, together with the composition of its lavas, its true origin and history may readily be made out. It has been named the Sherman volcano. This old volcano of early Tertiary time occupies a prominent place in the geological development of the park, and dates back to the earliest outbursts of lava which have in this region changed a depressed basin into an elevated plateau. We have here a volcano situated far inland, in an elevated region, in the heart of the Rocky Mountains. It lies on the eastern side of the continent, only a few miles from the great Continental Divide, which sends its waters to both the Atlantic and Pacific.

After the dying out of the andesitic and basaltic lavas, followed by a period of erosion, immense volumes of rhyolite were erupted, which not only threatened to fill the crater but to bury the outer walls of the volcano itself. On all sides the andesitic slopes were submerged beneath the rhyolite to a height of from 8,000 to 8,500 feet. This enormous mass of rhyolite, poured out after the close of the andesitic period, did more than anything else to bring about the present physical features of the park tableland. A tourist visiting all the prominent geyser basins, hot springs, Yellowstone Lake, and the Grand Canyon and Falls of the Yellowstone, is not likely to come upon any other rock than rhyolite, excepting, of course, deposits from the hot springs, unless he ascends Mount Washburn, A description of the rhyolite region is essentially one of the Central Plateau. Taking the bottom of the basin at 6,500 feet above sea level, these acidic lavas were piled up until the accumulated mass measured 2,000 feet in thickness. It completely encircled the Gallatin Range, burying its lower slopes on both the east and west sides; it banked up all along the west flanks of the Absarokas, and buried the outlying spurs of the Teton and the Wind River Plateaus.

The Central Plateau covers an area approximately 50 by 40 miles, with a mean altitude of 8,000 feet. It is accidented by undulating basins of varied outline and scored by deep canyons and gorges. Strictly speaking, it is not a plateau; at least it is by no means a level area, but a rugged country, characterized by bold escarpments and abrupt edges of mesa-like ridges. But few large vents or centers of volcanic activity for the rhyolite have been recognized, the two principal sources being the volcano to which reference has already been made and Mount Sheridan in the southern end of the park. Mount Sheridan is the most commanding peak on the plateau, with an elevation 10,385 feet above sea level and 2,600 feet above Heart Lake. From the summit of the peak on a clear day one may overlook the entire plateau country and the mountains which shut it in, while almost at the base of the peak lie the magnificent lakes which add so much to the quiet beauty of the region, in contrast to the rugged scenery of the mountains. From no point is the magnitude and grandeur of the volcanic region so impressive. The lava flows—bounded on the east by the Absarokas—extend westward not only across the park, but across the Madison Plateau, and out on to the great plains of Snake River, stretching far westward almost without a break in the continuity of eruptive flows. Over the central portion of the park, where the rhyolites are thickest, erosion has failed to penetrate to the underlying rock. Even such deep gorges as the Yellowstone, Gibbon, and Madison Canyons have nowhere worn through these rhyolite flows. In the Grand Canyon of the Yellowstone the andesitic breccias are found beneath the rhyolites, but the deepest cuts fail to reveal the underlying sedimentary beds. Although the rocks of the plateau for the most part belong to one group of acidic lavas, they by no means present the great uniformity and monotony in field appearance that might be expected. These 2,000 square miles offer as grand a field for the study of structural forms, development of crystallization, and mode of occurrence of acidic lavas as can be found anywhere in the world. They vary from a nearly holocrystalline rock to one of pure volcanic glass. Obsidian, pumice, pitchstone, ash, breccia, and an endless development of transition forms alternate with the more compact lithoidal lavas which make up the great mass of the rhyolite, and which in colors, texture, and structural developments present an equally varied aspect. In mineral composition these rocks are simple enough. The essential minerals are orthoclase and quartz, with more or less plagioclase. Sanidine is the prevailing feldspar, although in many cases plagioclase forms occur nearly as abundantly as orthoclase. Chemical analyses, whether we consider the rocks from the crater of Mount Sheridan, the summit of the plateau, or the volcanic glass of the world-renowned Obsinian Cliff, present comparatively slight differences in ultimate composition.

I have dwelt somewhat in detail upon the nature of these rocks for two reasons: First, because of the difficulty met with by the scientific traveler in recognizing the uniformity and simplicity of chemical composition of the rhyolite magma over the entire plateau, owing to its great diversity in superficial habit; second, on account of their geological importance in connection with the unrivaled display of the geysers and hot springs. That the energy of the steam and thermal waters dates well back into the period of volcanic action, there is in my opinion very little reason to doubt. As the energy of this underground heat is to-day one of the most impressive features of the country, I will defer commenting upon the geysers and hot springs until speaking of the present condition of the park.

OBSIDIAN CLIFF.

Although the rhyolite eruptions were probably of long duration and died out slowly, there is, I think, evidence to show that they occupied a clearly and sharply defined period between the andesites and late basalt eruptions. Since the outpouring of this enormous mass of rhyolite and building up of the plateau, the region has undergone faulting and displacement; immense blocks of lava have been lifted bodily, and the surface features of the country have been modified. Following the rhyolite came the period of late basalt eruptions, which, in comparison with the andesite and rhyolite eras, was, so far as the park was concerned, insignificant, both as regards the area covered by the basalt and its influence in modifying the physical aspect of the region. The basalt occurs as thin sheets overlying the rhyolite and in some instances as dikes cutting the more acidic rocks. It has broken out near the edge of the rhyolite body and occurs most frequently along the Yellowstone Valley, along the western foothills of the Gallatin Range and Madison Plateau, and again south of the Falls River Basin.

After the greater part of the basalt had been poured out came the glacial ice, which widened and deepened the preexisting drainage channels, cut profound gorges through the rhyolite lavas and modeled the two volcanoes into their present form. Over the greater part of the Cordillera of the central and northern Rocky Mountains, wherever the peaks attain a sufficiently high altitude to attract the moisture-laden clouds, evidences of the former existence of local glaciers are to be found. In the Teton Range several well-defined characteristic glaciers still exist upon the abrupt slopes of Mount Hayden and Mount Moran. They are the remnants of a much larger system of glaciers. The park region presents so broad a mass of elevated country that the entire plateau was, in glacial times, covered with a heavy capping of ice. Evidences of glacial action are everywhere to be seen.

Over the Absaroka Range glaciers were forced down into the Lamar and Yellowstone Valleys, thence westward over the top of Mount Everts to the Mammoth Hot Springs Basin. On the opposite side of the park the ice from the summit of the Gallatin Range moved eastward across Swan Valley and passing over the top of Terrace Mountain joined the ice field coming from the east. The united ice sheet plowed its way northward down the valley of the Gardiner to the Lower Yellowstone, where the broad valley may be seen strewn with the material transported from both the east and west rims of the park.

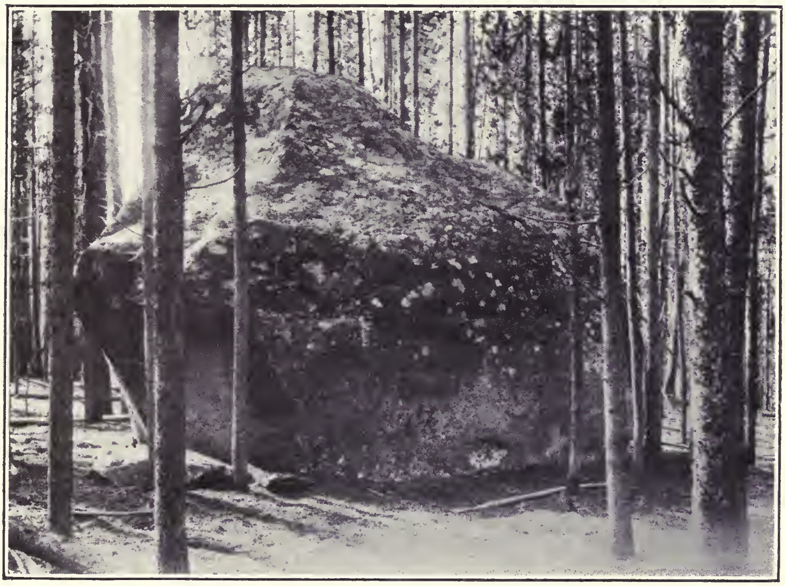
Since the dying out of the rhyolite eruptions erosion has greatly modified the entire surface features of the park. Some idea of the extent of this action may be realized when it is recalled that the deep canyons of the Yellowstone, Gibbon, and Madison Rivers—canyons in the strictest use of the word—have all been carved out since that time. To-day these gorges measure several miles in length and from 1,000 to 1,500 feet in depth.

To the geologist one of the most impressive objects on the park plateau is a transported bowlder of granite which rests directly upon the rhyolite near the brink of the Grand Canyon, about 3 miles below the falls of the Yellowstone. It stands alone in the forest, a long way from the nearest glacial bowlder. Glacial detritus carrying granitic material may be traced upon both sides of the canyon wall. This massive block, although irregular in shape and somewhat pointed toward the top, measures 24 feet in length by 20 feet in breadth and stands 18 feet above the base. The nearest point from which it could have been transported is distant 30 or 40 miles. Coming upon it in the solitude of the forest with all its strange surroundings it tells a most impressive story. In

* The Grand Teton.

no place are the evidences of frost and fire brought so forcibly together as in the Yellowstone National Park.

Since the close of the ice period no geological events of any moment have brought about any changes in the physical history of the region other than those produced by the direct action of steam and thermal waters. A few insignificant eruptions have probably occurred, but they failed to modify the broad outlines of topographical structure and present but little of general interest beyond the evidence of the continuance of volcanic action into quaternary times. Volcanic activity in the park may be considered as long since extinct. At all events indications of fresh lava flows within historical times are wholly wanting. This is not without interest, as evidence of underground heat may be observed everywhere throughout the park in the waters of the geysers and hot springs. All our observations point in one direction and lead to the theory that the cause of the high temperatures of these waters must be found in the heated rocks below, and that the origin of the heat is in some way associated with the source of volcanic energy. It by no means follows that the waters themselves are derived from any deep-seated source; on the contrary, investigation tends to show that the waters brought up by the geysers and hot springs are mainly surface waters which have percolated downward a sufficient distance to become heated by large volumes of steam ascending through fissures and vents from much greater depths. If this theory is correct it is but



GLACIAL BOWLDER NEAR GRAND CANYON.


111°00′
110°50′
110°40′
110°30′
110°20′
110°10′
110°00′
45° 00′
44° 50′
44° 40′
N. P. R. R.
Gardiner
NORTH ENTRANCE
GARDINER ROAD
TURKEYPEN TRAIL
Crevice Gulch
Knowles Station
Hellroaring Mt. 8300
HELLROARING TRAIL
MONTANA
WYOMING
LOWER YELLOWSTONE TRAIL
Hell Roaring Creek
BUFFALO PLATEAU
Buffalo Cr.
NORTHEAST ENTRANCE
Baronett Peak 10300
Abiathar Peak 10800
Sportsman Lake
Electric Pk. 11000
Sepulcher Mtn. 8700
Mammoth Hotel
FORT YELLOWSTONE
SNOW PASS TRAIL
GOLDEN GATE RD.
Kingman Pass
Bunsen Pk. 9100
BUNSEN PK. ROAD
Gardiner R.
Wylie Camp
COOKE ROAD
Deer Cr.
Blacktail
Lava Creek
Elk Cr.
Petrified Trees
Wylie Camp
Tower Falls Station
Tower Falls
Lost Cr.
Prospect Pk. 9400
SNOWY RANGE
Slough Cr.
Plateau Cr.
Creek
Bison Pk. 8800
COOKE
Lamar
Rose Cr
Druid Pk. 9600
SPECIMEN RIDGE
Amethyst Cr.
Pebble Cr.
ROAD
Creek
Amphitheater Cr.
Soda Butte
COOKE ROAD
The Thunderer 10400
The Needles 9600
Cache Creek
South Cache Cr.
River
Amethyst Mtn. 9400
Deep Creek
Shallow Cr.
MIRROR PLATEAU
Calfee Cr.
Miller Cr.
Fan Creek
Gallatin
GALLATIN TRAIL
River
Joseph Pk. 10400
Gray Pk. 10300
Fawn Pass 9100
Fawn Creek
GALLATIN RANGE
QUADRANT MTN.
Bannock Pk. 10400
Grayling Creek
CROWFOOT RIDGE
Bighorn Pass 8900
Antler Pk. 10200
Indian Cr.
Three Rivers Pk. 9900
Obsidian Cr.
PARK ROAD
Obsidian Lake
Apollinaris Spring
Obsidian Cliff
Beaver L
Creek
Cr.
White Pks. 9800
Tripolite Pt. 9800
Grizzly L.
Winter
Straight Cr.
WILLOW
Twin Lakes
Bijah Spring
Roaring Mtn. 8000
Frying Pan Springs
Solfatara
Storm Peak 9500
Tower Creek
Carnelian Cr.
TOWER FALLS RD.
Antelope Cr.
DUNRAVEN CUTOFF
Mt. Washburn 10000
Dunraven Peak 9700
Observation Pk. 9300
Grebe Lake
MT. WASHBURN ROAD
River
GRAND CANYON
Yellowstone
Gneiss Cr.
Maple
Cougar
Cr.
Norris Sta.
Norris Lunch Station
ROAD
Gibbon
Virginia Cascade
River
FREIGHT ROAD
CANYON ROAD
Canyon Ho.
Inspiration Pt.
Artist Pt.
Lower Falls 308 Feet
Upper Falls 109 Feet
Canyon Sta.
Wylie Camp
Chittenden Bridge
Broad Cr.
Wapiti Lake
Timothy Cr.
Willow Cr.
Saddle Mtn. 10000
Gibbon Meadows
Gibbon Hill 8600
Paintpot Hill 7900
CANYON
Secret Valley
GIBBON
Gibbon Falls 80 feet
Yellowstone
Stage Stables
Wylie Camp
O. S. L. R. R.
Riverside Station
MADISON RIVER RD.
FREIGHT ROAD
Madison R.
Purple Mtn. 8700
Wylie Lunch Station
Gibbon R.
MESA RD.
MESA TRAIL
Cascades of the Firehole
FIREHOLE RD.
River
Fountain Sta.
Perce
MARY MOUNTAIN TRAIL
Mary Lake
Magpie Cr.
CENTRAL PLATEAU
Alum Cr.
SULPHUR MTN. RD.
MARY MTN. RD.
YELLOWSTONE RIVER ROAD
HAYDEN VALLEY
Mud Geysers
Cotton Grass Cr.
Sour Cr.
Fern Lake
Tern Lake
White Lake
Stonetop Mt. 9000
Raven Creek
Mist Cr.
Cold Cr.
Pyramid Pk. 10300
ABSAROKA RANGE
BACK
TEAU

Sketch Map of the Yellowstone National Park.

A topographic map of the park on a scale of 2 miles to the inch may be purchased from the Director of the Geological Survey, Washington, D. C., for 20 cents.

fair to demand that evidence of long-continued action of hot waters and superheated steam should be apparent upon the rocks through which they passed on their way to the surface. This is precisely what one sees in innumerable places on the Central Plateau. Indeed, the decomposition of the lavas of the rhyolite plateau has proceeded, on a most gigantic scale, and could only have taken place after the lapse of an enormous period of time and the giving off of vast quantities of heat, if we are to judge at all by what we see going on around us to-day. The ascending currents of steam and hot water have been powerful geological agents, and have left an indelible impression upon the surface of the country. The most striking example of this action is found in the Grand Canyon of the Yellowstone. From the Lower Falls for 3 miles down the river abrupt walls upon both sides of the canyon, a thousand feet in depth, present a brilliancy and mingling of color beyond the power of description. From the brink of the canyon to the water's edge the walls are sheer bodies of decomposed rhyolite. Varied hues of orange, red, purple, and sulphur-yellow are irregularly blended in one confused mass. There is scarcely a piece of unaltered rock in place. Much of it is changed into kaolin; but from rhyolite, still easily recognized, occur transition products of every possible kind to good porcelain clay. This is the result of the long-continued action of steam and vapors upon the rhyolite lavas. Through this mass of decomposed rhyolite the course of ancient steam vents in their upward passage may still be traced, while at the bottom of the canyon hot springs, fumaroles, and steam vents are still more or less active, but probably with diminished power.

Still other areas are quite as convincing, if not on so grand a scale, as the Yellowstone Canyon. Josephs Coat Basin, on the east side of the canyon, and Brimstone Hills, on the east side of the Yellowstone Lake, an extensive area on the slopes of the Absaroka Range, both present evidences of the same chemical processes brought about in the same manner. It is not too strong a statement to make to say that the plateau on the east side of the Grand Canyon, from Broad Creek to Pelican Creek, is completely undermined by the action of superheated steam and alkaline waters on the rhyolite lava. Similar processes may be seen going on to-day in all the geyser basins. A long period of time must have been necessary to accomplish these changes. The study of comparatively fresh vents shows almost no change from year to year, although careful scrutiny during a period of five years detects a certain amount of disintegration, but infinitely small in comparison with the great bodies of altered rock. This is well shown in a locality like the Monarch Geyser in the Norris Geyser Basin, where the water is thrown out at regular intervals through a narrow fissure in the rock.

The Grand Canyon of the Yellowstone offers one of the most impressive examples of erosion on a grand scale within recent geological times.

It is self-evident that the deep canyon must be of much later origin than the rock through which it has been worn, and it seems quite clear that the course and outlines of the canyon were in great part determined by the easily eroded decomposed material forming the canyon walls, and this in turn was brought about by the slow processes just described.

The evidence of the antiquity of the hot spring deposits is, perhaps, shown in an equally striking manner and by a wholly different process of geological reasoning. Terrace Mountain is an outlying ridge of the rhyolite plateau just west of the Mammoth Hot Springs. It is covered on the summit with thick beds of travertine, among the oldest portions of the Mammoth Hot Springs deposits. It is the mode of occurrence of these calcareous deposits from the hot waters which has given the name to the mountain. Lying upon the surface of this travertine on the top of the mountain are found glacial bowlders brought from the summit of the Gallatin Range, 15 miles away, and transported on the ice sheet across Swan Valley and deposited on the top of the mountain, 700 feet above the intervening valley. It offers the strongest possible evidence that the travertine is older than the glacier which has strewn the country with transported material. How much travertine was eroded by the ice is, of course, impossible to say, but so friable a material would yield readily to glacial movement.

Still another method of arriving at the great antiquity of the thermal energy and the age of the hot spring formation is by determining the rate of deposition and measuring the thickness of the accumulated sinter. This method, although the one which would perhaps first suggest itself, is, in my opinion, by no means as satisfactory as the geological reasoning already given. It is unsatisfactory because no uniform rate of deposition can be ascertained for even a single area, like the Upper Geyser Basin, and it is still more difficult to arrive at any conclusion as to the growth of the sinter in the past. Moreover, it is quite possible that heavy deposits may have suffered erosion before the present sinter was laid down. It however corroborates other methods and possesses the advantage of being a direct way.

It may be well to add that there exists the greatest contrast between the deposits of the Mammoth Hot Springs and those found upon the plateau. At the Mammoth Springs they are nearly pure travertine, with only a trace of silica, analyses showing from 95 to 99 per cent of calcium carbonate. On the plateau, the deposits consist for the most part of siliceous sinter, locally termed "geyserite." The reason for the difference is this: At the Mammoth Hot Springs the steam, although ascending from fissures in the igneous rock, comes in contact with the waters found in the Mesozoic strata, which here form the surface rocks. The Jura or Cretaceous limestones have furnished the lime held in solution and precipitated on the surface as travertine. On the other hand, the mineral constituents of the plateau waters are derived almost

TERRACES AT MAMMOTH HOT SPRINGS.

exclusively from the highly acidic lavas, which carry but a small amount of lime.

Deposition of sinter from the hot waters of the geyser basins depends in a great measure on the amount of silica held in solution, which varies considerably at the different localities and may have varied still more in past time. The silica, as determined by analyses, ranges from 0.22 to 0.60 grammes per kilogram of water, the former being the amount found in the water of the caldron of the Excelsior Geyser and the latter at the Coral Spring in the Norris Basin. Analysis shows that from one-fifth to one-third of the mineral matter held in solution consists of silica, the remaining constituents being readily soluble salts carried off by surface drainage. A few springs highly charged with silica, like the Coral, deposit it on the cooling of the waters; but such springs are exceptional. At most springs and geysers it results after evaporation, and not from mere cooling of the water. It seems probable that the nature and amount of alkaline chlorides and carbonates present influence the separation of silica. Temperature also may in some degree influence the deposition. My friend, Mr. Elwood Hofer, has called my attention to an observation of his made in midwinter, while on one of his snowshoe trips through the park. He noticed that certain overflow pools of spring water, upon being frozen, deposited a considerable amount of mineral matter. He has sent me specimens of this material, which, upon examination, proved to be identical with the silica deposited from the Coral Spring upon the cooling of the water. Demijohns of geyser water which have been standing for one or two years have failed to precipitate any silica. Quite recently, in experimenting upon these waters in the laboratory, it was noticed that on reducing them nearly to the freezing point no change took place, but upon freezing the waters there was an abundant separation of free silica. The waters frozen in this way were collected from the Coral Spring, Norris Basin, and the Taurus Geyser, Shoshone Basin.

Again, there is no doubt that the algous growths flourishing in the hot waters of the park favor the secretion of silica and calcic carbonate and exert a potent influence in building up both the sinter and travertine deposits far greater than one might at first be led to suppose. These processes of assimilation are steadily taking place without interruption, as all algæ act as geological agents. The silica and lime brought to the surface by hot springs is, upon the death of the algæ, transformed into sinter and travertine, becoming rock masses, which later show scarcely any sign of their origin from plant life. Tourists are seldom aware that the harmonious and brilliant tints are due to vegetable growths. Algæ develop equally well in the waters of all geyser basins and upon the terraces of Mammoth Hot Springs. Water boils in the Upper Geyser Basin at 198° F., and rudimentary organisms appear at about 185° F., although no definite line can be drawn beyond which all life ceases.

These low vegetable organisms occur in nearly all pools, springs, and running water upon the plateau. Wherever boiling waters cool to the latter temperature algæ make their appearance, and with the lowering of temperature on exposure to air still more highly organized forms gradually come in. It is believed that at about 140° F. conditions are favorable for a rapid development of numerous species. Many forms of algæ flourish within restricted ranges of temperature, and the different species possess characteristic colors and habits of growth dependent upon such changes of temperature. After a little experience it is quite possible, upon noting the nature of the plant life, to make a sure guess as to the temperature of the water in which the species grow. As water in the geyser pools and caldrons frequently stands at or near the boiling point, no life exists at the centers of discharge, but with a rapid lowering of temperature algæ appear, with corresponding changes of color, in the shallow pools and overflow channels. In the geyser basins the first evidence of vegetation in an overflow stream consists of creamy white filamentary threads, passing into light flesh tints, then to deep salmon. With distance from the source of heat the prevailing colors pass from bright orange to yellow, yellowish green, and emerald, and in the still cooler waters various shades of brown. This, of course, is a simple statsment of phenomena which really display highly complex conditions. No two pools or overflow channels are quite alike in their occurrence either as regards flow of water or development of algæ.

ALGAE BASINS.

Several methods have been devised for ascertaining the growth of deposition of the geyserite. One way is by allowing the water to trickle over twigs, dried grasses, or almost anything exposing considerable surface, and noting the amount of incrustation. This way gives the most rapid results, but is far from satisfactory and by no means reproduces the conditions existing in nature. Other methods employed are placing objects on the surface of the water or, still better, partially submerging them in the hot pools, or again by allowing the water to run down an inclined plane with frequent intervals for evaporation and concentration.

The vandals who delight to inscribe their names in public places have invaded the geyser basins in large numbers and left their addresses upon the geyserite in various places. It is interesting to note how quickly these inscriptions become indelible by the deposition of the merest film of silica upon the lead-pencil marks, and, at the same time, how slowly they build up. Names and dates known to be 6 and 8 years old remain perfectly legible, and still retain the color and luster of the graphite. That there is some increase in the thickness of the incrustation is evident, although it grows with incredible slowness. Mr. Weed tells me that he has been able, in at least one instance, to chip off this siliceous film and reproduce the writing with all its original distinctness, showing conclusively that a slow deposition has taken place. Pencil inscriptions upon the siliceous sinter at Rotomahana Lake, in New Zealand, are said to be legible after the lapse of 20 or 30 years. It is easy to see that various ingenious devices might be planned to estimate the rate of deposition, but in my opinion none of them equal a close study of the conditions found in nature, especially where investigations of this kind can be watched from year to year. All observations show an exceedingly slow building up of the geyserite formation. This is well seen in the repair

BOWL OF GREAT FOUNTAIN GEYSER, LOWER GEYSER BASIN.

going on where the rims surrounding the hot pools have been broken down, and where it might be supposed that the building-up process was under the most favorable conditions; yet, in a number of instances, I can see no appreciable change in three or four years. Revisiting hot springs in out-of-the-way places after several years' absence, I am surprised to see that objects that I had noted carefully at the time remain unchanged. Taking the entire area of the Upper Geyser Basin covered by sinter, I believe that the development of the deposit does not exceed one-thirtieth of an inch a year, and this estimate I believe to be much nearer the maximum than the minimum rate of growth. Supposing the deposit around Castle Geyser to have been built up with the same slowness as observed to-day, and assuming it to grow at the rate given—one-thirtieth of an inch a year—it would require over 25,000 years to reach its present development. This gives us a great antiquity for the geyserite, but I believe that the deposition of the siliceous sinter in the park has been going on for a still longer period of time. It is certain that the decomposition of the rhyolite of the plateau dates still further back.

CONE OF CASTLE GEYSER, UPPER GEYSER BASIN.

From a geological point of view, there is abundant evidence that thermal energy is gradually becoming extinct. Tourists revisiting the park after an absence of two or three years occasionally allude to the springs and geysers as being less active than formerly and as showing indications of rapidly dying out. It is true that slight changes are constantly taking place, that certain springs become extinct or discharge less water, but this action is fully counterbalanced by increased activity in other localities. Close examination of the source of the thermal waters fails to detect any diminution in the supply. Moreover, it stands to reason that if the flow of these waters dated—geologically speaking—far back into the past, the few years embraced within the historical records of the park would be unable to indicate any perceptible change based upon a gradual diminution of the heat.

The number of geysers, hot springs, mudpots, and paintpots scattered over the park exceeds 3,000, and if to these be added the fumaroles and solfataras, from which issue in the aggregate enormous volumes of steam and acid and sulphur vapors, the number of active vents would in all probability be doubled. Each one of these vents is a center of decomposition of the acid lavas. The following list comprises the principal geysers known in the Norris, Lower, and Upper Geyser Basins.

Norris Geyser Basin—16.

Arsenic,
Constant,
Echinus,
Fearless,
Fissure (New Crater),
Growler,
Hurricane,
Minute,
Monarch,
Pearl,
Pebble,
Schlammkessel,
Valentine,
Veteran,
Vixen,
Whirligig.

Lower Geyser Basin—23.

Bead,
Clepsystra.
Cliff,
Conch,
Excelsior,
Fountain,
Fitful,
Flood,
Great Fountain,
Impulsive,
Jet,
Kaleidoscope,
Mound,
Narcissus,
Pink Cone,
Rabbit,
Spasm,
Spray,
Steady,
Surprise,
Tromp,
White Dome,
Young Hopeful.

Upper Geyser Basin—45.

Artemesia,
Bee Hive,
Bijou,
Bonita,
Brilliant,
Bulger,
Cascade,
Castle,
Catfish,
Comet,
Cub (Big),
Cub (Little),
Daisy,
Economic,
Fan,
Giant,
Giantess,
Grand,
Grotto,
Infant,
Liberty,
Lion,
Lioness,
Mastiff,
Midget,
Model,
Mortar,
Oblong,
Old Faithful,
Restless,
Riverside,
Rocket,
Sawmill,
Sentinel,
Spasmodic,
Spanker,
Spiteful,
Splendid,
Sponge,
Spouter,
Sprinkler,
Sprite,
Tardy,
Triplets,
Turban.

A comparative study of the analyses of the fresh rhyolite, the various transition products, and the thermal waters points clearly to the fact that the solid contents of these waters are derived for the most part from the volcanic rocks of the plateau. During the progress of the work of the Geological Survey in the Yellowstone Park there have been collected from many of the more important localities samples of the waters, which have been subjected to searching chemical analyses in the laboratory of the survey, by Messrs. F. A. Gooch and J. E. Whitfield

They are all siliceous alkaline waters holding the same mineral constituents, but in varying qualities. Silica forms the principal deposit, not only immediately around the springs but over the entire floor of the basins. The carbonates, sulphates, chlorides, and traces of other easily soluble salts are carried off in the waters. Oxides of iron and manganese and occasionally some calcite occur under certain conditions in the caldrons of the hot springs or immediately around their vents. Concentrations from large quantites of these waters fail to show the presence of even a trace of copper, silver, tin, or other metal. Nearly all the waters carry arsenic, the amount present, according to Messrs. Gooch and Whitfield, varying from 0.02 to 0.25 per cent of the mineral matter in solution.

Among the incrustations found at several of the hot springs and geysers is a leek-green amorphous mineral, which proves on investigation to be scorodite, a hydrous arseniate of iron. The best occurrence observed is at Josephs Coat Springs, on the east side of the Grand Canyon of the Yellowstone, where it occurs as a coating upon the siliceous sinter lining the caldron of a boiling spring. Analysis shows a nearly pure scorodite, agreeing closely with the theoretical composition:

Ferric oxide	34.94
Arsenic acid	48.79
Water	16.27
	100.00

Alteration of the scorodite into limonite takes place readily, which in turn undergoes disintegration by the wearing of the water, and is mechanically carried away. So far as I know, this is the only occurrence where scorodite has been recognized as deposited from the waters of thermal springs. Although pure scorodite is only sparingly preserved at a few localities in the Yellowstone Park, it is easily recognized by its characteristic green color, in strong contrast with the white geyserite and yellow and red oxides of iron. After a little practice the mineral green of scorodite is not easily mistaken for the vegetable green of the algeous growths. The latter is associated everywhere with the hot waters, while the former, a rare mineral, is obtained only in small quantities after diligent search. In America traces of arsenic have been reported from several springs in Virginia, and quite recently sodium arseniate has been detected in the hot springs of Ashe County, N. C. Arsenical waters of sufficient strength to be beneficial for remedial purposes and not otherwise deleterious are of rare occurrence. In France the curative properties of arsenical waters have been long recognized, and the famous sanitarium of La Bourboule, in the volcanic district of the Auvergne, has achieved a wide reputation for the efficacy of its waters in certain forms of nervous diseases. Hygeia Springs carries 0.3 of a grain of sodium arseniate to the gallon. The Yellowstone Park waters, while they carry somewhat less arsenic than those of La Bourboule, greatly exceed the latter in their enormous overflow. It is stated that the entire discharge from the springs of La Bourboule amounts to 1,500 gallons per minute. The amount of hot water brought to the surface by the hot springs throughout the park is by no means easily determined, although during the progress of investigations I hope to make an approximate estimate. According to the most accurate measurements which could be made, the discharge from the caldron of the Excelsior Geyser amounted to 4,400 gallons of boiling water per minute. The sample of the Excelsior Geyser water collected August 25, 1884, yielded 0.19 grain of sodium arsenate to the gallon. It is impossible to say as yet what curative properties these park waters may possess in alleviating the ills of mankind. Nothing but an extended experience under proper medical supervision can determine.

Changes modifying the surface features of the park in recent times are mainly those resulting from the filling up with detrital material of the valleys and depressions worn out by glacial ice, and those produced by the prevailing climatic conditions. Between the park country and what is known as the arid regions of the West there is the greatest possible contrast. Across the Central Plateau and the Absaroka Range the country presents a continuous mountain mass 75 miles in width, with an average elevation unsurpassed by any area of equal extent in the northern Rocky Mountains. It is exceptionally situated to collect the moisture-laden clouds, which coming from the southwest precipitate immense quantities of snow and rain upon the cooled tableland and neighboring mountains. The climate in many respects is quite unlike that found in the adjacent country, as is shown by the meteorological records, the amount of snow and rainfall being higher, and the mean annual temperature lower. Rainstorms occur frequently throughout the summer, while snow is quite likely to fall any time between September and May. Protected by the forests the deep snows of winter lie upon the plateau well into midsummer, while at still higher altitudes, in sheltered places, it remains throughout the year. By its topographical structure the park is designed by nature as a reservoir for receiving, storing, and distributing an exceptional water supply, not exceded by any area near the headwaters of the great continental rivers. The Continental Divide, separating the waters of the Atlantic from those of the Pacific, crosses the park plateau from southeast to northwest. On both sides of this divide lie several large bodies of water, which form so marked a feature in the scenery of the plateau that the region has been designated the lake country of the park. Yellowstone Lake, the largest lake in North America at this altitude (7,740 feet) and one of the largest in the world at so high an elevation above sea level, presents a superficial area of 139 square miles, and a shore line of nearly 100 miles. From measurements made near the outlet of the lake in September, 1886, the driest period of the year, the discharge was found to be 1,525 cubic feet per second, or about 34,000,000 imperial gallons per hour.

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